Memory

INTENDED LEARNING OBJECTIVES (ILOs)

By the end of this lecture the student will be able to:

- ✓ Classify memory
- ✓ List the types of memory
- ✓ Compare short-term and long-term memory
- ✓ Compare declarative and non-declarative memory
- ✓ List the sites for memory storage in the brain
- ✓ Describe the role of synaptic plasticity in memory

Memory and learning

Learning: It is acquisition of knowledge or skills that alter behaviors or performance as a result of experience, instruction or both.

Memory: is the retention and storage of that information for later recall.

Classification of memory:

A. Temporal Classification of Memory:

Memory can be categorized according to the time over which it is effective.

1. Immediate memory
2. Short term memory
3. Long term memory

Immediate Memory:

It is the ability of the brain to hold onto ongoing experience for **a second** or so. For example, immediately when close your eyes you can recall a good deal of information from the image you last saw.
Attention is needed to transfer information to short-term memory.

Short-term Memory

1. It is formed immediately from immediate memory by mental or verbal repetition of information
2. It **lasts for seconds** to **hours.**
3. It is **limited** in both **duration** and **capacity**
4. It takes **short time** to **retrieve** the information.
5. It has one of two fates. Either it is **rapidly and permanently forgotten** or as a result of repeated **rehearsal**, it **transferred into long-term memory**, by a process called **consolidation**.

6. It is **more vulnerable**, the memory traces can be disrupted by trauma, various drugs and passage of a large electrical current across the skull, as in electroconvulsive therapy.
7. **Working memory** is a form of short-term memory that makes information available for a brief period while individual plans other actions based on it e.g. ***handling phone while repeating the number.***
8. The mechanism of short-term memory is **transient** modifications in the **function of preexisting synapses**, for example a temporary change in the amount of neurotransmitter released in response to stimulation or temporary change responsiveness of the postsynaptic cell to the neurotransmitter within affected nerve pathways.

   The activity of preexisting synapses changes through **post tetanic potentiation**, **short-term habituation** or **short-term sensitization**

Long-term Memory

1. It is formed later from short-term memory through consolidation which is enhanced by practice or rehearsal
2. It stores information **for years**, and sometimes **for life.**
3. It has **very large capacity**.

Different informational aspects of long-term memory traces seem to be processed, codified, and then stored with other memories of the same type. In another word memory is not like taking a photograph and placing it drawer to be withdrawn later (recalled) exactly as you originally placed it there (stored). But memory is more like taking a picture and tearing it up into small pieces and putting the pieces in different drawers. The memory is then recalled by reconstructing the memory from the individual fragments of the memory.

4. Because long-term memory stores are larger, it often takes **longer** time to **retrieve** the information
5. Fate: information in long-term storage is **forgotten only temporarily**. For example, you may be transiently unable to remember an acquaintance's name but it suddenly "come to you". Some forms of long-term memory involving **information** or **skills used daily** are thoroughly ingrained and **never forgotten** and are **rapidly accessible** e.g. knowing your name or being able to write
6. Long-term memory traces are remarkably **resistant to disruption**
7. The mechanism of long-term memory involves relatively **permanent functional or structural changes** between existing neurons in the brain as it is resistance to disruption. Through **activation of specific genes** that control synthesis of proteins, needed for the permanent structural or functional changes at the synapses. These changes includes **formation of new synaptic connections** by increase the number of **dendritic spines** or the **number of synapses on the dendrites** of postsynaptic neurons,

Increase **enzymes inducing transmitter synthesis**, Increase number of **transmitter vesicles**, Increase number of transmitter **releasing sites**, addition of **more receptor sites**,

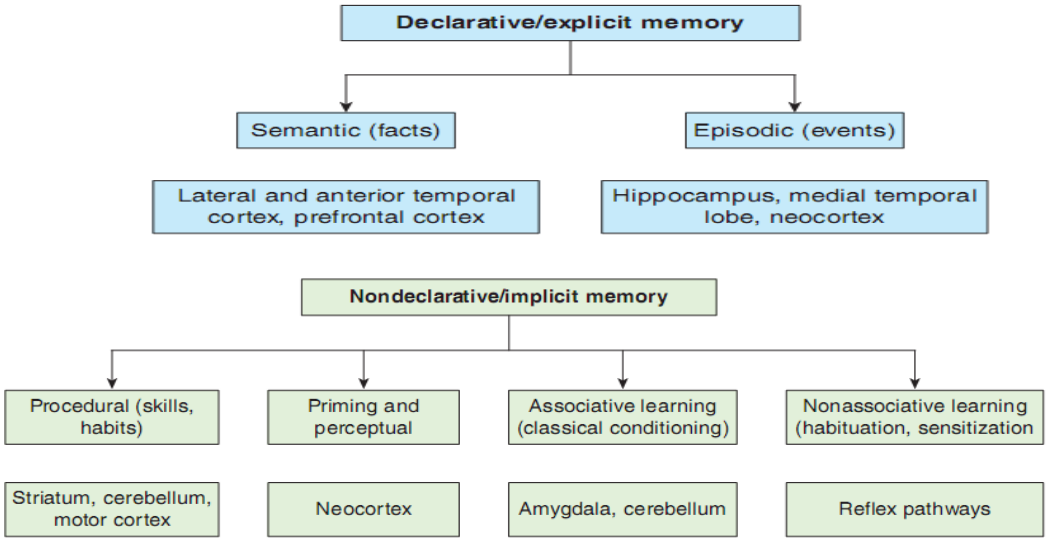
The activity of the permanent synapse changes through **long term potentiation, long-term habituation** or **long-term sensitization**

B. Physiological classification:

Based on type of information stored how it is stored and recalled

I. **Explicit memory** (Conscious) = Declarative (recognition) memory

II. **Implicit memory** (Unconscious) = Procedural memory = Non declarative (Reflexive) memory



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I. Explicit memory (Conscious) = Declarative (recognition) memory

- It is the memory for factual knowledge about people, places, and things ***(Memory of what).***
- ***Declarative*** as It is easy to "declare" or to discuss verbally while ***explicit*** because it is result from more conscious effort.
- Conscious and awareness is essential for its recall.
- Depend on **hippocampus** and retained in medial temporal lobe of the brain, neocortex and prefrontal cortex.
- Declarative memories are often **easy to form** and are **easily forgotten**.
- Declarative memory is of two types: semantic and episodic
  - ***a. Semantic memory*** is recall of general memories (facts, concepts, rules, words and language) e.g., Cairo is the capital of Egypt.
  - **b.** ***Episodic memory*** is recall of personal memories (memory of events and experiences) e.g., I went to amazing concert last year.

II. Implicit memory (Unconscious) = Procedural memory = Non declarative (Reflexive) memory

- It is the memory for training reflexive motor or perceptual skills, tasks and habits ***(Memory of how to do things).***
- ***Non declarative*** as it is not easily declared or discussed verbally while ***implicit*** because it is results from direct experience.
- It does **not** need awareness (unconscious)
- Its retention does ***not*** usually involve processing in the hippocampus.
- Forming nondeclarative memories usually **require repetition** and practice over a **longer period**, but these memories are **less likely to be forgotten**.
- It is of 4 types:
  a. ***Priming:*** it is the facilitation of the recognition of words or objects by prior exposure to them.
     It is dependent on the **neocortex** e.g. recall of a word when presented with the first few letters of it.
  b. ***Procedural memory:*** includes skills and habits, which, once acquired, become unconscious and automatic e.g. learn to play the piano, learn to ride a bicycle or tie your shoes.
     It is processed in the **striatum and cerebellum.**
  c. ***Non-Associative learning:*** a stimulus, given once or repeatedly, provides an experience which leads to learning rather than the formation of connections between elements or events. It includes ***habituation*** (decrease the response with repeated unimportant stimulus) and ***sensitization*** (augmented response to previously habituated stimulus).
     It is dependent on **various reflex pathways.**
  d. ***Associative learning:*** A type of learning that involves the formation of a connection between two elements or events. It includes ***classical conditioning*** (learning a relationship between two stimuli e.g. Pavlov's experiment or observing repeatedly that dark clouds are followed by rain makes us learn that dark clouds lead to rain. So, the next time we see dark clouds while leaving home, we carry an umbrella) and ***operant conditioning*** (it is the use of consequences, reward or punishment, to modify the occurrence and form of behavior e.g., car driver slows down and stops the car on seeing red traffic light and drive on when seeing the green light).
     This type of memory is dependent on the **amygdala** for its emotional responses and the **cerebellum** for the motor responses.

For reading

Classical conditioning: involves learning a relationship between two stimuli.

A conditioned reflex is a reflex response to neutral stimuli that normally do not produce response. A conditioned response is acquired by repeated pairing of stimulus that normally does not produce the response called **conditioned stimulus (CS)** with another stimulus that naturally produces the response called **unconditioned stimulus (US)** e.g. Pavlov's experiments.

In this experiment, a dog is presented with food which it likes, its mouth starts salivation. Food is **UCS** for the salivation reflex. Now a bell is rung near the dog. The sound of the bell does not lead to salivation. But if the bell is immediately followed by food a few hundred times, the dog learns to expect food after the bell. Therefore, now the bell alone also leads to salivation. Sound of the bell is called the **CS** for the salivation reflex.

Neurophysiology: A conceptual approach, fifth edition 2013

Operant conditioning: it is the use of consequences (reward or avoid punishment) to modify the occurrence and form of behavior.

The person or animal are taught to perform a specific task to obtain reward or avoid punishment.

For example, when rat is placed Inside a box has a bar-shaped lever on one side, it first explores its surroundings out of curiosity. In the process, sooner or later, it hits the bar. Pressing the bar may lead to a reward, releases food pellet, (reinforcement) or a punishment (e.g. an electric shock). If it leads to a reward, the rat presses it again and again. If it leads to a punishment, the rat avoids pressing the bar.

Memory traces are present in multiple regions of the brain:

There is **no single "memory center"** in the brain. Instead, the neurons involved in memory traces are widely distributed throughout the subcortical and cortical regions of the brain.

- Declarative memory ⟶ **hippocampus** and retained in **medial temporal lobe** of the brain, **neocortex** and **prefrontal cortex**.
- Priming ⟶ **neocortex**
- Procedural memory ⟶ **striatum and cerebellum**
- Associative learning ⟶ **amygdala** for its emotional responses and the **cerebellum** for the motor responses
- Non-Associative learning ⟶ **various reflex pathways**

The hippocampus plays an especially important role in declarative memories and encoding of short-term memories into long-term memories

Role of synaptic plasticity in memory

1- Post-tetanic potentiation:

It is enhanced response of postsynaptic neuron to a brief tetanic train of stimuli. This enhancement lasts for seconds.

It is the basis of **short-term memory**

Mechanism:

Increase neurotransmitter release due to accumulation of Ca^{2+} in the presynaptic neuron caused by the tetanizing stimulation.

2- Habituation:

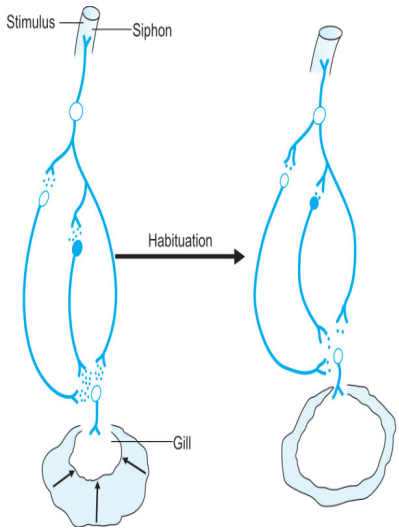
It is gradual **decrease in response** with repetition of insignificant stimulus. It is the most common form of learning (non-associative learning).

It can be **short term**, or it can be **long term** if exposure to the benign stimulus is repeated many times

The person become habituated and ignores the insignificant stimulus, e.g. sleeping in noise ignoring the sound of dogs.

Mechanism:

Gradual inactivation of Ca^{2+} channels at **presynaptic neuron** by repeated stimulation → ↓ Ca^{2+} in presynaptic neuron → ↓ **release of neurotransmitter** from presynaptic neurons.



Understanding medical physiology: A textbook of medical physiology, fourth edition, Jaypee, 2011

3- Sensitization:

It is progressive **amplification** of a response to a previous habituated stimulus when it is coupled one or more with unpleasant stimulus, e.g. person bitten by dog avoids all dogs.

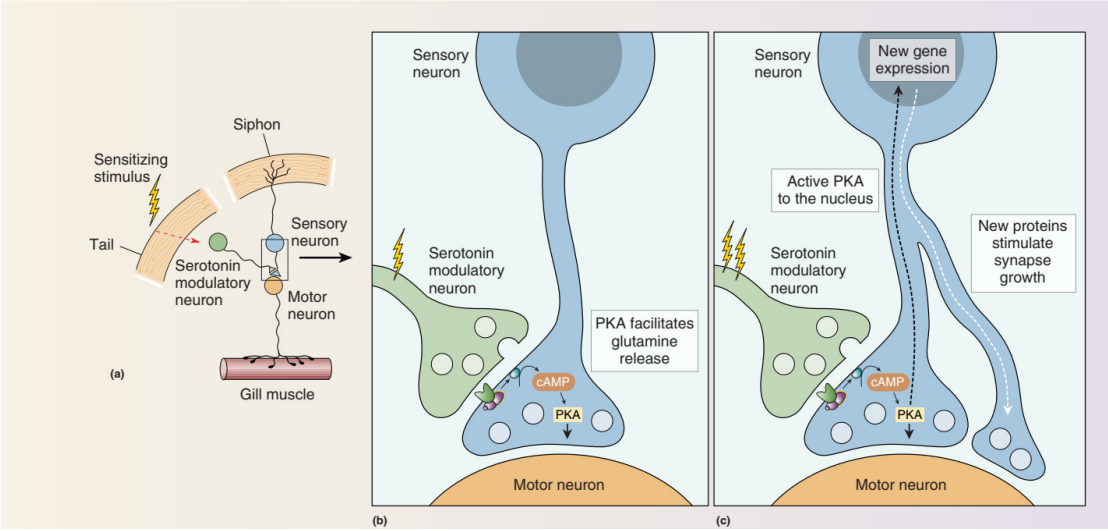
Like habituation, sensitization is also both **short-term** and **long term**, depending on the degree of exposure to the sensitizing stimulus

Mechanism: **(presynaptic facilitation)**

The noxious stimulus causes activation of **serotonergic** interneurons which act on the presynaptic sensory neurons to facilitate it

Serotonin acts on the presynaptic terminal to increase cAMP

Increased cAMP → closure of K^+ channels → decrease K^+ efflux→ prolongation of action potentials at presynaptic neurons → opens Ca^{2+} channels → **increase Ca^{2+} influx** → **increased transmitter release** by the synapse.



NEUROSCIENCE EXPLORING THE BRAIN Fourth Edition, 2016 Wolters Kluwer

Short-term sensitization

long-term sensitization

4- Long-term potentiation (LTP):

It is persistent enhancement of synaptic efficacy of **both presynaptic (greater transmitter release)** and **postsynaptic (greater sensitivity to transmitter)** neurons following a brief period of rapidly repeated stimulation of the presynaptic neuron.

Such changes can **persist for days to weeks**, long enough for the short-term memory to be **consolidated** into more permanent long-term memory.

LTP occurs in many parts of the nervous system but are most prominent in the **hippocampus**, a site critical for converting short-term memories into long-term memories

Mechanism:

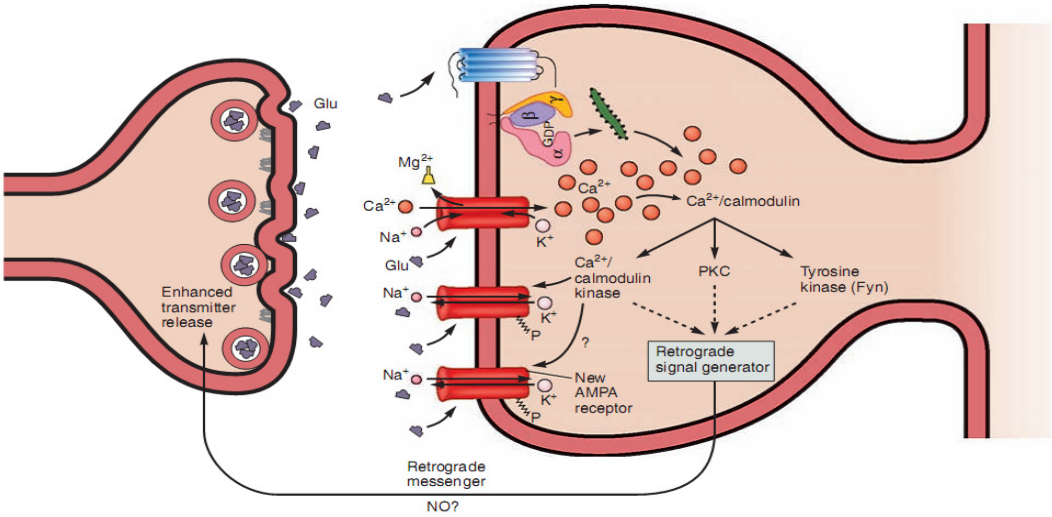
LTP is initiated by an increase the entry of Ca^{2+} in postsynaptic neuron. Ca^{2+} entrance occurs through NMDA receptor of glutamate

Ca^{2+} entrance activates protein kinases which phosphorylates the proteins essential for the induction of long-term potentiation causing movement of

more receptors to the synaptic membrane from the cytosolic storage site and increasing their conduction.

After appropriate stimulation of a presynaptic pathway, the number of dendritic spines and the number of synapses on the dendrites of postsynaptic neurons increase rapidly increasing the connection between the presynaptic and postsynaptic neurons.

Also, nitric oxide is released by the postsynaptic neuron, it passes retrogradely to the presynaptic neuron and causes long-term increase in the release of glutamate.



Ganong's Review of Medical Physiology Twenty-fifth Edition, 2016

SUGGESTED TEXTBOOKS

1. Ganong's Review of Medical Physiology, twenty-fifth edition 2016, McGraw-Hill Education, chapter 15, from page 283 to 295.

2. Human Physiology: From Cells to Systems, Ninth edition 2016. by CENGAGE, chapter 5, from page 157 to 163 Lauralee Sherwood

3. NEUROSCIENCE, sixth edition 2018, Oxford University Press, chapter 30, from page 681 to 702.